



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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<b>(21) International Application Number:</b> PCT/US93/12316 <b>(22) International Filing Date:</b> 16 December 1993 (16.12.93)  <b>(30) Priority Data:</b> 07/996,050                      23 December 1992 (23.12.92)      US  <b>(71) Applicant:</b> ELECTRIC POWER RESEARCH INSTITUTE, INC. [US/US]; 3412 Hillview Avenue, Palo Alto, CA 94303 (US).  <b>(72) Inventors:</b> CROUCH-BAKER, Steven; 3120 Louis Road, Palo Alto, CA 94303 (US). McKUBRE, Michael, C., H.; 112 Durham Street, Menlo Park, CA 94025 (US). SMEDLEY, Stuart, I.; 364 O'Connor Street, Menlo Park, CA 94025 (US). TANZELLA, Francis, I.; 935 Buckland Avenue, San Carlos, CA 94070 (US).  <b>(74) Agents:</b> GALLIANI, William, S. et al.; Flehr, Hohbach, Test, Albritton & Herbert, 4 Embarcadero Center, Suite 3400, San Francisco, CA 94111-4187 (US).		<b>(81) Designated States:</b> AU, CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.          Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
<b>(54) Title:</b> APPARATUS FOR STORING ISOTOPES OF HYDROGEN		
<b>(57) Abstract</b>		
<p>An electrolysis system (1) for altering the storage capacity of a metal cathode for hydrogen isotopes has a direct current source (11) coupled between an anode (9) and a cathode (7), with both electrodes (9, 7) at least partially immersed in an electrolyte (5). The current source (11) drives electric current through the electrolyte (5) from the anode (9) to the cathode (7). The electrolyte (5) is typically a solution of lithium deuterioxide and boric acid in heavy water. The metal cathode (7) is typically comprised primarily of palladium. The current flow through the cell (12, 67) causes the palladium to become loaded with boron and deuterium, which substantially increases the efficiency of excess heat production and lowers the current threshold for excess heat generation. In an alternative version, the surface of the cathode (7) is fabricated from an alloy of boron and palladium.</p> <div data-bbox="889 1121 1446 1898" data-label="Diagram"> </div>		

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APPARATUS FOR STORING ISOTOPES OF HYDROGENCross-References To Related Applications

This is a continuation-in-part of U.S. patent application Serial No. 07/722,094, filed June 27, 1991.

- 5 This application concerns subject matter that is related to the subject matter disclosed in the following U.S. patent applications:

1. USSN 07/714,388, filed June 11, 1991.
2. USSN 07/714,380, filed June 11, 1991.
- 10 3. USSN 07/714,383, filed June 11, 1991.
4. USSN 07/713,976, filed June 11, 1991.
5. USSN 07/722,098, filed June 27, 1991.
6. USSN \_\_\_\_\_, filed December 10, 1992.

Background Of The Invention15 1. *Field of the Invention*

This invention pertains generally to the field of devices for storing isotopes of hydrogen, and more particularly, to such devices where the hydrogen is generated by electrochemical means.

## 2. Description of Background Art

It is recognized that certain metals and alloys form compounds with hydrogen isotopes which are useful for the storage of hydrogen. Hydrogen storage systems are useful when one wishes to subsequently oxidize the hydrogen to produce energy, e.g., in fuel cells and batteries used for transportation purposes. In this connection, the electrochemical charging of metal cathodes with hydrogen isotopes is a known method for producing these so-called "hydrogen storage alloys."

In general, hydrogen storage systems of the type under consideration here function by accommodating hydrogen atoms in interstitial locations in the metal or alloy lattice. Under ordinary conditions, it is usually not possible to access all the available interstitial locations. Thus, only a part of the available hydrogen storage capacity is realized. This invention describes a means for treating a metal cathode such that access is increased to hydrogen storage locations within the metal cathode, which locations are otherwise only partly accessible. This can be important, since the hydrogen storage capacity of the cathode may be affected by this process. In addition, this method of treatment can be important because excess power evolution has been observed during the electrochemical loading of the hydrogen isotope deuterium into a palladium cathode which has been treated in this manner.

Fleischmann et al., "Electrochemically Induced Nuclear Fusion of Deuterium", Journal of Electroanalytical Chemistry, Vol. 261, p. 301 (April 1989), describes calorimetric measurements on electrochemical cells with platinum anodes and palladium cathodes driven by a source of electric current through the cell. The electrolytes contained heavy water, and deuterium from the electrolyte was loaded into the palladium cathodes. Depending on the

amount of electric current, it was found that these cells generated anomalously large quantities of heat.

In the calorimetry experiments of these authors and the other experiments discussed herein, one compares the known and measured sources of input energy or power to the system with the observed output energy or power. The difference between the output energy and input energy is defined as the "excess heat."

Similar calorimetry experiments have also been carried out to detect indications of nuclear processes. The state of this art in 1990 was summarized in the Proceedings of The First Annual Conference on Cold Fusion, March 28 - 31, 1990, Salt Lake City, Utah. Similarly, the state of the art in 1991 was summarized in the Proceedings of The Second Annual Conference on Cold Fusion, June 29 to July 4, 1991, Como, Italy.

Heat-producing cells have been constructed using a variety of materials for the electrodes and the electrolyte. In particular, cells have been constructed with electrolytes that contain LiOD (lithium deuterioxide), NaOD, KOD, Fe, Ag, Hg, Li<sub>2</sub>SO<sub>4</sub> (lithium sulphate), As<sub>2</sub>O<sub>3</sub>, and uranium, in addition to heavy water. Lithium deuterioxide is a commonly used electrolytic ingredient.

Cathodes have been fabricated from titanium and a variety of palladium alloys, besides pure palladium. These alloys include palladium-silver, palladium-lithium, palladium-carbon, palladium-lithium-carbon, palladium-beryllium, and palladium-sulphur. Reference is made to the paper by E. Storms and C. Talcott entitled "A Study of Electrolytic Tritium Production", on page 149 of the first above-mentioned conference proceedings, summarizing the results obtained from cells using a variety of cathode materials.

In particular, these authors report that two cathodes have been fabricated from an alloy of palladium-boron. The alloy was made by arc-melting palladium powder with boron in an argon atmosphere. The atomic ratio of boron to palladium was B/Pd = 0.028. One cathode was used in a cell having  $\text{As}_2\text{O}_3$  in the electrolyte, and a small amount of tritium was produced. The other cathode was operated in a cell with ordinary electrolyte; no tritium was produced. In neither case were there any observations of excess heat. The authors' conclusions are that the effect of a Pd-B alloy is uncertain, although under certain conditions the chance of tritium production seems to be improved.

#### Disclosure of Invention

The present invention provides an electrolysis system 1 for altering the storage capacity of a metal cathode for hydrogen isotopes, having a direct current source 11 coupled between an anode 9 and a cathode 7, with both electrodes immersed in an electrolyte 5 in container 3. The current source 11 drives electric current through the electrolyte 5 from anode 9 to cathode 7. The electrolyte 5 is a solution of lithium deuterioide and boric acid in heavy water ( $\text{D}_2\text{O}$ ). The cathode 7 is comprised primarily of palladium. The current flow through the cell causes the palladium to become loaded with boron and deuterium. It is found that this charging of boron into the cathode 7 substantially increases the efficiency of production of excess heat, and lowers the current threshold for excess heat generation, compared to cells without boron.

The cathode 7 may include other elements besides palladium, deuterium and boron. Generally, the cathode 7 also contains lithium from the LiOD in the electrolyte 5. Other alloys of palladium such as Pd-Ag may be used as the host material. The distinctive feature of boron is that in the palladium crystal lattice it occupies octahedral interstitial sites

which might otherwise be occupied by deuterium. This enhances the excess heat production process.

It is an object of this invention to provide a device for altering the storage capacity of a metal cathode for  
5 hydrogen isotopes.

A second object of this invention is to provide a device for generating excess heat by the electrochemical charging of palladium alloys with deuterium.

Another object of this invention is to provide a device for  
10 generating excess heat having an improved efficiency for the production of such excess heat.

Another object of this invention is to provide a device for generating excess heat in which the current threshold for excess heat production is substantially decreased.

15 These and other objects, advantages, characteristics and features of this invention may be better understood by examining the following drawings together with the detailed description of the preferred embodiments.

#### Brief Description Of The Drawings

20 FIG. 1 is a schematic diagram of an electrolysis system 1 for generating excess heat according to the present invention, showing a partially cross-sectioned elevational view of an electrolytic cell 12 embodying the invention;

FIG. 2 is a diagram of the face-centered cubic (FCC) crystal  
25 lattice structure of alloys of palladium that are useful in this invention, showing octahedral and tetrahedral interstitial sites on which alloy atoms may reside, for example; and

FIG. 3 is a cross-sectional front view of an electrolytic cell 67 embodying the present invention.

#### Detailed Description Of The Preferred Embodiments

FIG. 1 is a schematic diagram of an electrolysis system 1 for generating excess heat according to the present invention, for loading deuterium into a palladium alloy cathode 7. This cathode 7 and an anode 9 are immersed in an electrolyte 5 in container 3. The cathode 7 and anode 9 are coupled to a current generator 11 which drives a direct current from the anode 9 to the cathode 7 within the electrolyte 5. The entire system may be enclosed in a sealed enclosure 2, which may also serve as a heat exchanger or may comprise various heat exchange devices, well known in the art, for extracting and transferring heat from the system.

The electrolyte 5 contains heavy water, specifically  $D_2O$ , and also preferably  $LiOD$ , typically a 1 molar solution. In the preferred embodiment, boric acid,  $H_3BO_3$ , is added to this solution to provide a source of boron for loading into the cathode 7. This cathode 7 is preferably fabricated from palladium; however various alloys of palladium may also be used, such as palladium-silver. Furthermore, boron may be preloaded into the cathode 7, in which case Pd-B is the alloy. Finally, since the active region of the cathode 7 is in the vicinity of the surface, the cathode 7 may actually be a layer of palladium alloy over a bulk region of a conducting metal having a small deuterium diffusivity, such as copper. The anode 9 is preferably fabricated from palladium, platinum, or some stable non-elemental metallic conductor material.

The bulk palladium used in practicing the invention should be of high purity. It is desirable to anneal out crystal imperfections and volatilize impurities, and to minimize stresses that may lead to cracks in the palladium surface



which will limit the attainable amount of deuterium loading. Oxidation of the surface by  $O_2$  or  $H_2O$  should also be avoided for the same reason. Preferably, the palladium is annealed in a vacuum furnace at  $800^\circ C$  for three hours and then  
5 allowed to cool in one atmosphere of  $D_2$  gas or argon. After cooling, the Pd surface is etched in deuterated aqua regia, and then rinsed in  $D_2O$ .

It is also desirable to minimize the amount of  $H_2O$ ,  $O_2$ , and  $CO_2$  in the electrolyte 5. Preferably, the solution is  
10 formed by allowing pure Li metal or  $Li_2O$  to react with  $D_2O$  of high isotopic purity in an inert gas environment.

The electrolyte container 3 should be fabricated from materials that will not form deposits on the surface of the cathode 7 that inhibit the degree of deuterium loading. Two  
15 examples of materials that are satisfactory are quartz glass and polytetrafluoroethylene (PTFE).

The cathode 7 is preferably precharged at a moderate current density (between  $10 \text{ mA/cm}^2$  and  $100 \text{ mA/cm}^2$ ) for a time corresponding to several diffusion periods of deuterium in  
20 palladium. This time is typically 3 to 10 days. This precharging period facilitates the subsequent accumulation of deuterium in the cathode. The production of excess heat is then initiated by increasing the current density continuously up to a threshold level. This threshold level  
25 may be as low as  $1 \text{ mA/cm}^2$ .

Referring now to FIG. 2, at standard temperature and pressure palladium is known to have a face-centered cubic (FCC) crystal structure, which is illustrated in this figure. The FCC lattice sites are indicated by the circles  
30 having horizontal hatchings. These sites are the locations of the palladium atoms in the crystal. Many alloys of palladium, such as Pd-Ag, also have this crystal structure. Palladium-silver is a substitutional alloy, in which the

silver atoms occupy FCC lattice sites that would otherwise be occupied by palladium atoms.

The distinctive feature of deuterium (hydrogen) and boron is that these elements form interstitial alloys in palladium.

5 (The term "alloys" is used here in its generalized sense of solid solutions, and is not limited to any specific fabrication process.) The palladium-hydrogen system has been extensively studied, and it is known that palladium has a propensity to absorb hydrogen, and that the hydrogen atoms

10 preferably occupy the octahedral interstitial sites in the palladium lattice. These sites lie in the horizontal and vertical planes defined by the lattice sites, and each octahedral site lies midway between two neighboring lattice sites, as indicated in FIG. 2 by the open circles. At a

15 stoichiometric ratio of one-to-one, if all the octahedral sites are occupied by hydrogen atoms, it will be seen from the figure that the hydrogen atoms form an interpenetrating FCC lattice within the palladium lattice. These remarks about the behavior of hydrogen apply also to deuterium,

20 since the chemical properties of both atoms are identical.

The octahedral sites are not the only available sites for interstitial atoms to occupy. In FIG. 2, the circles with diagonal hatching define the tetrahedral sites in the lattice. The names of these sites refer to the symmetry of

25 their atomic environment. For example, at the octahedral sites the "nearest neighbor" palladium atoms (i.e., the palladium atoms closest to the site) define surrounding planes forming an octahedron, and thus these sites have "octahedral symmetry." The tetrahedral sites have a lower

30 symmetry than the octahedral sites, and atoms at these sites have a higher energy. Therefore, the octahedral sites are preferably occupied by the interstitial atoms, but at any finite temperature there is always some occupation of tetrahedral sites as well. Furthermore, hydrogen can be

35 loaded at an atomic ratio of H/Pd greater than unity.

The palladium-boron system has also been studied, and reference is made to the article by H. A. Brodowsky and H.-J. Schaller, "Thermodynamics of Nonstoichiometric Interstitial Alloys. I. Boron in Palladium", Transactions of the Metallurgical Society of AIME, Vol. 246, p. 1015 (May 5 1969). These authors have analyzed the thermodynamic measurements of the palladium-boron system up to concentrations of 23 percent boron, and determined that the boron atoms also occupy the octahedral interstitial sites in 10 the palladium lattice. Their analysis further indicated that the energy gap between the octahedral sites and the tetrahedral sites is substantially greater for boron than for hydrogen (deuterium).

These considerations imply that the effect of loading boron 15 into the palladium lattice together with deuterium is that octahedral interstitial sites are occupied by boron atoms, and therefore blocked off from deuterium occupancy. For a given deuterium loading, the addition of boron causes deuterium atoms to be displaced from octahedral sites to 20 other interstitial locations, such as tetrahedral sites. Alternatively, at a given boron loading, deuterium atoms occupy more non-octahedral interstitial sites as the deuterium loading increases.

The increased occupancy of non-octahedral sites by deuterium 25 atoms decreases the average distance between neighboring deuterium atoms in the lattice, according to the diagram in FIG. 2. In the palladium lattice, the nearest neighbor octahedral sites are at a distance of 0.28 nanometers apart, while the corresponding nearest neighbor tetrahedral sites 30 are at a distance of 0.19 nm from each other, and the corresponding nearest neighbor octahedral-tetrahedral distance is 0.17 nm. These numbers must be adjusted to take account of the variation in lattice parameters with boron and deuterium concentration, and the phase changes that 35 occur in the solid solutions when the concentrations are increased to the phase boundaries. These corrections do not

alter the overall conclusion that the addition of boron decreases the average D-D nearest neighbor distances. This decrease is associated with the production of excess heat in the present invention.

- 5 FIG. 3 is a cross sectional front view of an electrolytic cell 67 embodying the present invention. This cell operates at approximately atmospheric pressure. Vessel 69 is constructed of aluminum and has a cylindrical sleeve shape with an internal surface of PTFE. The palladium cathode 55  
10 is disposed along the central axis of the vessel 69. This cathode 55 is a 3 mm diameter 3 cm long rod, machined from 1/8" pure Pd wire. Prior to insertion, the cathode 55 is solvent cleaned, vacuum annealed at 800°C for between 2 hours and 3 hours, and slowly cooled in an argon atmosphere.  
15 Finally it is dipped in heavy aqua regia for 20 seconds and rinsed with heavy water.

The electrolysis portion of the cell 67 is exposed only to materials from the group comprising Pd, Pt, quartz glass, and PTFE. Anode 65 consists of a one meter long, 0.5 mm  
20 diameter, Pt wire wound around a cage 73 of five quartz glass rods held in place by two PTFE disks 75. The wire 65 is held in place by attachment to 2 mm Pd mounting posts 79 mounted on the top PTFE disk 75. The electrolyte 71 separates the cathode 55 and anode 65. Reference electrode  
25 63 is adjacent to cathode 55.

Platinum wires 99 act as electrical feedthroughs in order to connect the cathode 55, anode 65, and reference electrode 63 to the power source 11 and other electrical measurement apparatus. One of the electrical feedthroughs 99 connects  
30 the cathode 55 to the negative terminal of the power source 11, and another electrical feedthrough 99 connects the anode 65 to the positive terminal of the power source 11.

All surfaces of the cell 67 are solvent cleaned and rinsed. The anode cage 73 is further washed with aqua regia and

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rinsed with  $D_2O$ . An external 180 ohm heater is wound around the outside of vessel 69 within specially machined grooves on the surface 59 of vessel 69. These grooves are omitted from the drawing of FIG. 3. The cell 67 is assembled with  
5 minimum exposure to air or moisture.

The electrolyte 71 is preferably prepared immediately prior to use and added to the vessel 69 before sealing the cell 67. In the illustrated embodiment, tube 81 is a 1/8" outside diameter nickel tube. The vessel 69 is preferably  
10 pressurized with deuterium.

To illustrate the operation of the invention, calorimetry experiments were performed with this apparatus using two different electrolytes 71, differing only in the inclusion of boron in one case and its omission in the other. The  
15 boron-free electrolyte was a 1.0 M solution of LiOD in heavy water with 200 ppm (molar) Al, manufactured by adding 0.175 g of Li metal and approximately 7 mg of pure Al foil to 25 ml  $D_2O$ . This procedure was carried out under a nitrogen atmosphere.

20 A calorimetry experiment was performed with this boron-free electrolyte 71 over a total duration of 1630 hours. Excess heat was first observed after 308 hours of electrolysis and was observed on ten separate occasions. In all cases, the production of excess heat was initiated during and persisted  
25 after the conclusion of an increasing current ramp. The maximum excess power observed was 1.0 watt (10% in excess of the input power); the total excess of energy was 1.08 megajoules (MJ), or 45 MJ/mole of Pd.

The second experiment was performed using the same apparatus  
30 but with boric acid added to the electrolyte 71. The addition of the order of 0.2 millimoles of  $H_3BO_3$  produced surface regions in the cathode that were loaded with boron to at least 10 atomic percent. This experiment was carried out over a total duration of 1287 hours. Excess heat was

first observed after 658 hours of electrolysis and was observed on three separate occasions. The maximum excess power observed was 0.8 watts (300% in excess of the input power); the total excess of energy was 0.25 MJ, or 11 MJ/mole of Pd. In comparing the observations from these two experiments, it is found that the addition of boron to the electrolyte 71 coincided with the following effects:

1. The excess heat production was initiated spontaneously, rather than during a period of increasing current.
2. The initiation occurred at substantially lower current density than in the case where boron-free electrolyte was used.
3. Excess heat production terminated while the current was still at a high value.

While the above description of the preferred embodiments discloses one technique for the inclusion of boron in the electrolyte 71, other methods could be utilized to achieve the loading of boron into the cathode 7. The cathode may be fabricated as a palladium-boron alloy before assembly into the cell 12, 67. Furthermore, other palladium alloys, such as Pd/Ag, having a similar FCC crystal structure can be used in place of pure palladium for loading with boron and deuterium.

Finally, the use of boron per se is not intended to be limiting, since other materials that occupy octahedral interstitial sites in the palladium lattice could accomplish the same result. For example, the alloy  $\text{PdC}_{0.15}$  contains carbon atoms on octahedral interstitial sites, as demonstrated experimentally using powder neutron diffraction. S. B. Ziemecki, G. A. Jones, D. G. Swartzfager, and R. L. Harlow, Journal of the American Chemical Society, Vol. 107, pp. 4547-4548 (1985). Therefore, carbon is a good candidate to substitute for boron.

The foregoing description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and many modifications and variations are possible in light of the above teaching. The embodiment has been chosen and described in order to best explain the principles of the invention and its practical applications to thereby enable others skilled in the art to best utilize the invention in various embodiments and with various modifications as are suitable to the particular use contemplated. It is intended that the spirit and scope of the invention are to be defined by reference to the claims appended hereto.

WHAT IS CLAIMED IS:

1. Apparatus for altering the storage capacity of a metal cathode for hydrogen isotopes, said apparatus comprising:  
an electrolyte comprising a hydrogen isotope and  
5 conducting ions;  
at least partially immersed in the electrolyte, an anode for interacting with conducting ions within the electrolyte;  
at least partially immersed in the electrolyte, a  
10 cathode having a metal alloy surface, said hydrogen isotope accumulating within the cathode surface, wherein said alloy has regions that include boron in an atomic ratio of boron to metal that is substantially greater than 0.028; and  
current generating means coupled to said anode and to  
15 said cathode, for producing an electric current in said electrolyte.
2. Apparatus for producing heat, said apparatus comprising:  
an electrolyte comprising deuterium and conducting  
20 ions;  
at least partially immersed in the electrolyte, an anode for interacting with conducting ions within the electrolyte;  
at least partially immersed in the electrolyte, a  
25 cathode having a palladium alloy surface, said deuterium accumulating within the cathode surface, wherein said alloy has regions that include boron in an atomic ratio of boron to palladium that is substantially greater than 0.028; and  
current generating means coupled to said anode and  
30 to said cathode, for producing an electric current in said electrolyte.
3. Apparatus as recited in claim 2, wherein the current produced by said current generating means causes deuterium to be loaded into said cathode.



4. Apparatus as recited in claim 2, wherein said atomic ratio of boron to palladium in said alloy is at least 0.10.

5. Apparatus for producing heat, said apparatus comprising:

5 an electrolyte comprising deuterium and conducting ions, wherein said conducting ions contain boron;

at least partially immersed in the electrolyte, an anode for interacting with conducting ions within the electrolyte;

10 at least partially immersed in the electrolyte, a cathode having a palladium surface, said deuterium and said boron accumulating within the cathode surface; and

current generating means coupled to said anode and to said cathode, for producing an electric current in said  
15 electrolyte.

6. Apparatus as recited in claim 5, wherein the current produced by said current generating means causes deuterium and boron to be loaded into said cathode.

7. Apparatus as recited in claim 5, wherein said boron is  
20 produced by dissolving a soluble compound containing boron in said electrolyte.

8. Apparatus as recited in claim 7, wherein said soluble compound comprises boric acid.

9. Apparatus for producing heat, said apparatus  
25 comprising:

an electrolyte comprising deuterium and conducting ions;

at least partially immersed in the electrolyte, an anode for interacting with conducting ions within the  
30 electrolyte;

at least partially immersed in the electrolyte, a cathode having a palladium alloy surface, said deuterium accumulating within the cathode surface, wherein said alloy

is an interstitial alloy with a host lattice having a face centered cubic crystal structure and with solute atoms occupying octahedral sites within said host lattice; and

current generating means coupled to said anode and to  
5 said cathode, for producing an electric current in said electrolyte.

10. Apparatus as recited in claim 9, wherein said solute atoms comprise boron.

11. Apparatus as recited in claim 9, wherein the atoms  
10 occupying said host lattice sites comprise a substitutional alloy of palladium.

12. Apparatus as recited in claim 11, wherein said substitutional alloy comprises palladium-silver.

13. Apparatus for producing heat, said apparatus  
15 comprising:

an electrolyte comprising deuterium and conducting ions, wherein said conducting ions contain an elemental species that forms an interstitial alloy with palladium and resides on octahedral sites in said interstitial alloy;

20 at least partially immersed in the electrolyte, an anode for interacting with conducting ions within the electrolyte;

at least partially immersed in the electrolyte, a cathode having a palladium surface, said deuterium and said  
25 elemental species accumulating within the cathode surface; and

current generating means coupled to said anode and to said cathode, for producing an electric current in said electrolyte.

30 14. Apparatus as recited in claim 13, wherein said elemental species comprises boron.

15. Apparatus as recited in claim 13, wherein said elemental species comprises carbon.

16. Apparatus as recited in claim 13, wherein the current produced by said current generating means causes deuterium  
5 and said elemental species to be loaded into said cathode.

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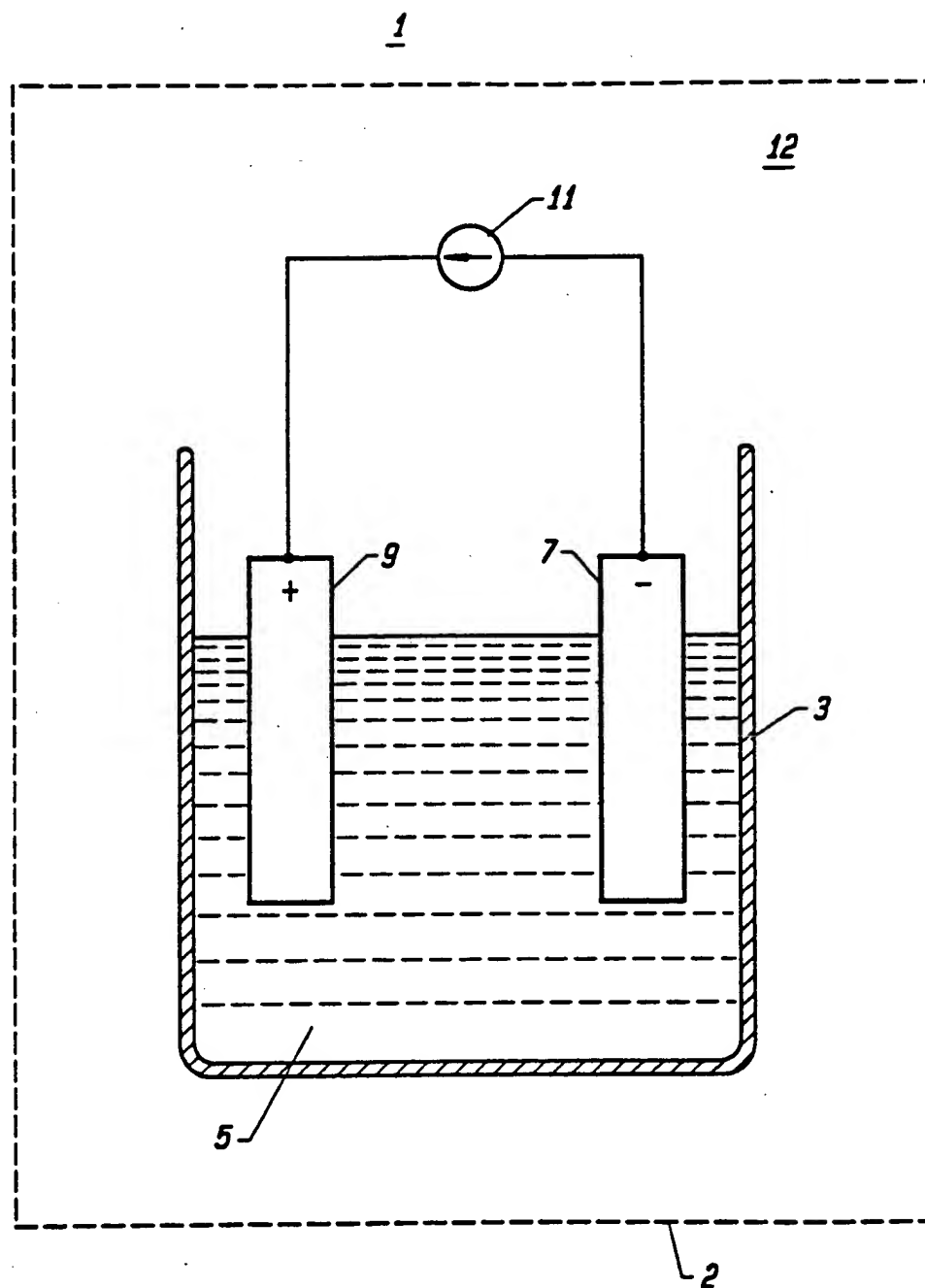


FIG. 1

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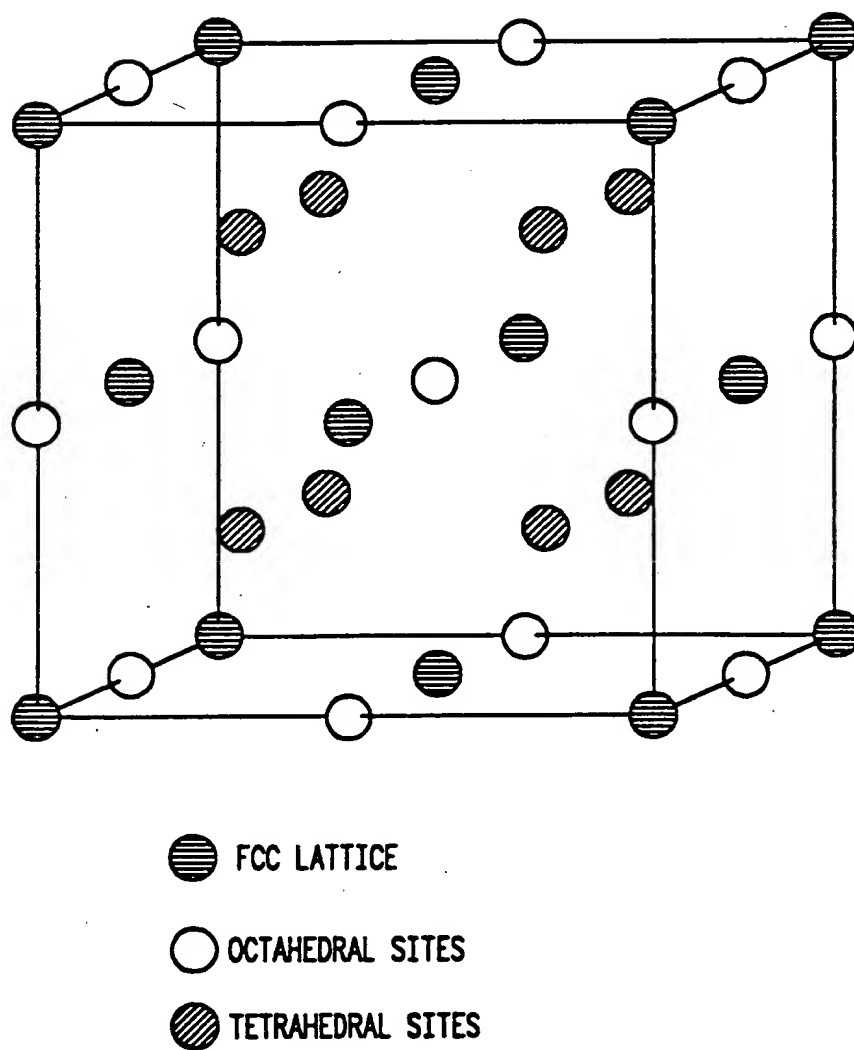


FIG. 2

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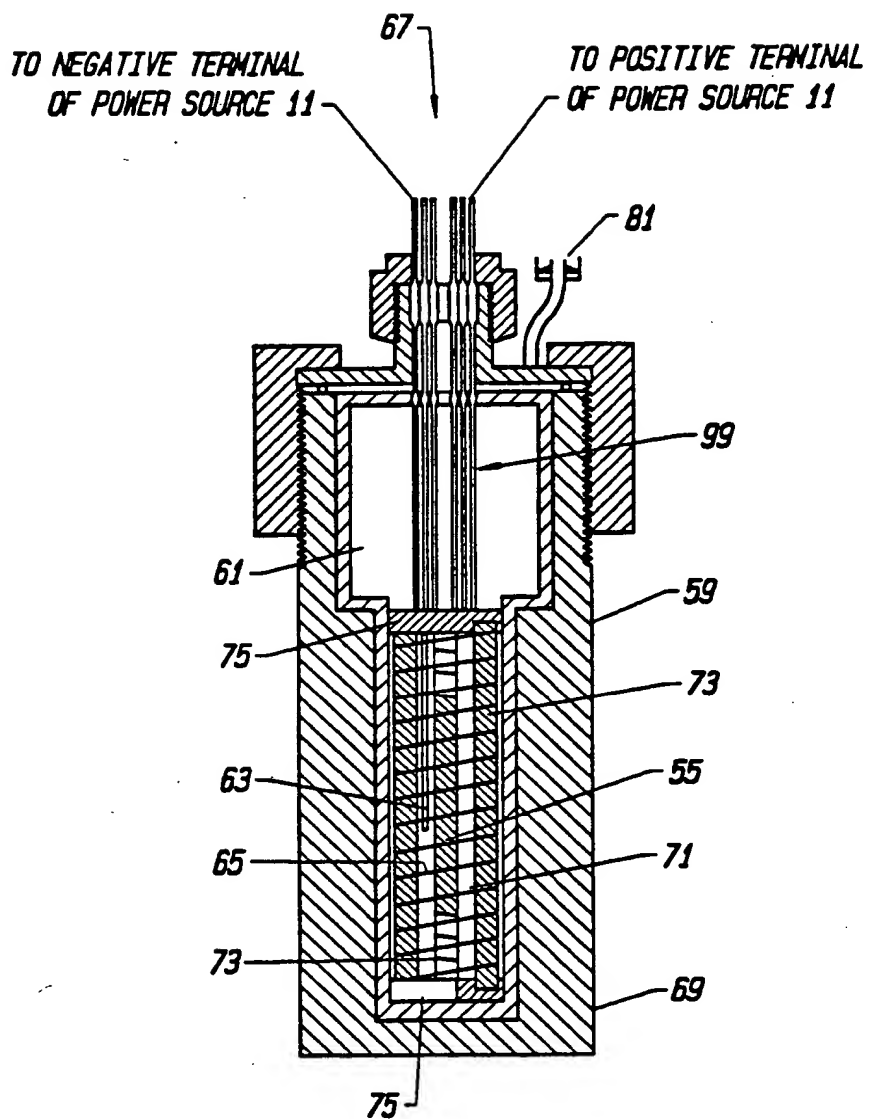


FIG. 3

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US93/12316

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(5) : G21B 1/00 US CL : 376/100 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) U.S. : 376/100 US 376/146; 420/900; 204/129, 262, 274, 204/290R, 290F, 292, 293 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US,A, 4,986,887 (GUPTA ET AL) 22 January 1991	1-10, 13, 14, 16 ----- 11, 12
X -- Y	JP,A, 2,268,288 (OKADA) 01 November 1990, (see the English language abstract)	1-10, 13, 14, 16 ----- 11, 12
X -- Y	The First Annual Conference on Cold Fusion. (Conf. Proc.) 28-31 March 1990, Salt Lake City, Utah, pages 149-163, Storms et al	9-12 ----- 1-4
Y	Phys. Lett. vol,51A, No. 3, 24 Feb. 1975, pages 147, 148, STRITZKER ET AL	1-4, 9-12
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: *A* document defining the general state of the art which is not considered to be part of particular relevance *E* earlier document published on or after the international filing date *F* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *G* document referring to an oral disclosure, use, exhibition or other means *H* document published prior to the international filing date but later than the priority date claimed *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art *&* document member of the same patent family		
Date of the actual completion of the international search 12 APRIL 1994		Date of mailing of the international search report MAY 11 1994
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer <i>Diane Gooding JR</i> HARVEY BEHREND Telephone No. (703) 308-0439

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US93/12316

(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Trans. of The Metallurgical Society of AIME, vol. 245, May 1969, pages 1015-1020, Brodowsky et al	1-4, 9-12
Y	Ber. Bunsen ges. Physik. Chem. vol. 77, (1973), pages 36-41, Mehlmann et al.	1-4, 9-12
Y	Z. Naturforsch. vol 23a, (1968), pages 1693-1694, Husemann et al	1-4, 9-12
Y	US,A, 4,048,383 (CLIFFORD) 13 September 1977 (note col. 29)	11, 12
L	Nature, vol. 340, 17 August 1989, pages 525-530, Lewis et al, (cited as casting doubt on inducing nuclear fusion by forcing deuterium in to palladium)	1-14, 16
L	J. of Fusion Energy, vol. 9, No. 3, September 1990, pages 263-268, Myers et al, (cited as casting doubt on inducing nuclear fusion by forcing deuterium into palladium).	1-14, 16
L	Nature, vol. 342, 23 November 1989, pages 375-384, Williams et al, (cited as casting doubt on inducing nuclear fusion by forcing deuterium into palladium).	1-14, 16



# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US93/12316

## Box I (Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet))

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II (Observations where unity of invention is lacking (Continuation of item 2 of first sheet))

This International Searching Authority found multiple inventions in this international application, as follows:

- I. The embodiment utilizing boron (claims 1-14, 16)
- II. The embodiment utilizing carbon (claims 9, 11, 12, 13, 15, 16)

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims: it is covered by claims Nos.:  
1-14, 16

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.  
☐ No protest accompanied the payment of additional search fees.